



August 18, 2011

Ms. Nancy J. Rumrill  
Environmental Engineer  
Groundwater Office – WTR-9  
United States Environmental Protection Agency  
75 Hawthorne Street  
San Francisco, California 94105

**Subject:** Supplemental Data and Information Regarding the Groundwater Model Prepared in Support of Curis Resources (Arizona) Inc. Application to Amend Underground Injection Control Permit (UIC No. AZ396000001)

Dear Ms. Rumrill:

Submitted herewith are data and information supporting the application (Application) to amend Underground Injection Control (UIC) Permit AZ396000001 (UIC Permit) filed with the United States Environmental Protection Agency (USEPA) on March 25, 2011 regarding the Florence Copper Project (FCP). This submittal includes data and information requested by you and Mr. Jim Walker during a conference call held on July 27, 2011. The data and information are organized in the order in which they were requested.

#### **Thickness of Model Layers**

USEPA requested information regarding the thickness of the layer used in creating the sub-regional scale groundwater flow model described in Attachment 14A of *Curis Resources (Arizona) Inc. Application to Amend Aquifer Protection Permit (APP) No. 101704*. Submittal of the application to amend APP No. 101704 coincides with the application to amend the UIC Permit and was thus provided to USEPA as supporting material.

The model described in Attachment 14A of the application to amend APP No. 101704 was partially based on the sub-regional groundwater flow model developed to support the original APP application in 1996. However, advances in modeling software and computing power since that time have facilitated substantial improvements of the current model over the model developed in 1996. One of the primary model improvements includes the ability to contour model layers to reflect actual geologic conditions, rather than depicting all geologic units using horizontal planar layers of uniform thickness.

The 1996 groundwater flow model used a uniform layer thickness that resulted in horizontal planar formation contacts and required differentiation of hydraulic parameters within each model layer to reflect non-horizontal formation contacts.

The current model includes 10 layers, distributed as follows:

- Layers 1 and 2 represent the Upper Basin Fill Unit (UBFU);
- Layer 3 represents the Middle Fine Grained Unit (MFGU);
- Layers 4 and 5 represent the Lower Basin Fill Unit (LBFU); and
- Layers 6 through 10 represent the Oxide Bedrock Unit.



Where multiple model layers are used to depict a single formation, the observed formation thickness was equally divided throughout to create model layers that reflect the variation of hydraulic properties observed in each geologic unit.

All on-site formation contact elevations were derived from geologic logs of core holes and wells drilled on site. Off-site formation contact elevations were derived either from model layers published by the Arizona Department of Water Resources (ADWR) (1990), or from publicly available ADWR water well records.

Ranges of the variable thickness of each model layer are given below:

- Layer 1: 10 to 183 feet
- Layer 2: 10 to 183 feet
- Layer 3: 10 to 904 feet
- Layer 4: 7.5 to 653 feet
- Layer 5: 7.5 to 653 feet
- Layer 6: uniform 40 feet
- Layer 7: 15 to 259 feet
- Layer 8: 15 to 259 feet
- Layer 9: 15 to 259 feet
- Layer 10: 15 to 259 feet

Model layers 1 through 5 extend throughout the entire 125 square mile model domain. Because the Oxide Bedrock Unit occupies the uppermost portion of an uplifted structural block of bedrock that exists almost entirely within the LBFU, model layers 6 through 10 do not extend beyond the limits of the structural block and thus do not extend throughout the entire model domain.

The variability in the thickness of model layers 1 through 5 outside of the FCP site reflects geologic data embodied in the ADWR (1990) Pinal AMA groundwater flow model and data available from ADWR well records. Within the FCP site, the thicknesses of model layers 1 through 5 were derived from on-site corehole data.

Layer 3, which represents the MFGU, shows substantial variability due to the fact the MFGU thickens significantly at the southern edge of the model domain, and continues to thicken to the south of the model domain. At the FCP site, the MFGU maintains a fairly uniform thickness of 40 to 60 feet.

Model layer 6, which represents the uppermost 40 feet of the Oxide Bedrock Unit, which is excluded from injection under the current UIC Permit, is the only model layer of uniform thickness. Layer 6 is contoured to reflect relief observed at the contact between the LBFU and the Oxide Bedrock Unit.

### **Advection and Dispersion within the Groundwater Flow Model**

USEPA requested that we summarize how advection and dispersion were addressed within the current groundwater flow model.

#### **Advection**

Advective flow is a property of solute transport that is represented in the model by the average linear velocity of groundwater flow, which is a function of Darcian velocity and effective porosity of the porous media. Pure advective transport of solutes in groundwater reflects the distance that a solute may migrate in the absence of mechanical dispersion, and results in a sharp concentration front moving through the formation by plug flow.

In the current FCP groundwater flow model, advective transport of solutes is allowed to proceed without any retardation factor, solute degradation, transformation processes, or other modification that might reduce the distance that solutes will migrate under pure advective flow conditions. No parameters were specifically input into the model to adjust advective flow magnitudes. This approach is deemed to be conservative, allowing sulfate to migrate as far as aquifer parameters and water budget fluxes will permit.

### **Dispersion**

The consideration of dispersive flux is also a conservative measure with respect to maximum sulfate migration distance, as it allows solute mass to proceed ahead of the sharp concentration front moving through the aquifer by pure advective flow. Within the MT3D model code, a longitudinal dispersivity value of 10 feet was used uniformly throughout the FCP groundwater flow model domain.

Dispersivity is a scale dependent property that defines the characteristic distance at which heterogeneities are present within the model domain, given the resolution and discretization of model construction. Because all sulfate mass was initially emplaced within the model layers comprising the oxide unit at the In Situ Copper Recovery (ASCR) area and the model cell spacing at the ISCR was 50 feet by 50 feet, a dispersivity value of 10 feet was deemed appropriate for a characteristic length of heterogeneities.

Because the FCP model construction includes refined layering in both the basin fill porous media and underlying oxide/sulfide geologic units, this dispersivity value was deemed to be appropriate to reflect the dispersion of sulfate mass through the fractured bedrock material under advective flow conditions and is well within the range of dispersivity values commonly used for a model of this level of grid and geologic refinement.

It should be noted that the model construction itself also allows for the hydrodynamic mixing of water between various aquifer units, such as the LBFU and Oxide Bedrock Unit. This mixing and blending of water is in addition to the dispersion assumed to be occurring within the fractures of the oxide. Following groundwater modeling convention, the lateral and vertical dispersivity values were set at 0.1 and 0.01 the value of longitudinal dispersivity, respectively, or 1 foot and 0.1 foot. The use of these dispersivity terms allow for solute mass to also disperse in directions perpendicular to solute flow.

### **Horizontal and Vertical Hydraulic Conductivities**

USEPA requested that we describe the basis for the 10:1 and 100:1 ratios of horizontal to vertical hydraulic conductivities used in the UBFU and LBFU, and MFGU respectively.

A horizontal to vertical hydraulic conductivity ratio of 10:1 or 100:1 is commonly used to describe vertical anisotropy ratios in the development of groundwater flow models. These ratios are used industry wide as an initial assumption during model construction and are adjusted during model calibration to improve the agreement between observed and simulated water levels in shallow and deeper aquifer units. For the FCP groundwater model, the final vertical anisotropy ratios for hydraulic conductivity were derived from 1) an understanding of the geologic conditions under which each hydrostratigraphic unit was deposited, and 2) the model calibration process.

Unconsolidated basin fill materials, such as those that comprise the UBFU and LBFU, were deposited by fluvial processes along primarily horizontal bedding planes. Sequences of finer (lower conductivity) and coarser (higher conductivity) materials are deposited on top of each other and have substantially greater lateral continuity than vertical thickness. This layering and interbedding of lower conductivity materials within an aquifer or hydrostratigraphic unit means that water has a greater ability to move

horizontally, or parallel to the bedding of higher conductivity units than it does to move vertically across interbedded or bounding low permeability material comprised of clays and/or silts.

Given the fact that typical hydraulic conductivity values for various porous media of various lithologies vary by orders of magnitude, a general assumption of a vertical anisotropy ratio of 10:1 or 100:1 is well within the range of reasonable conditions when various lithologies are interbedded. Additionally, as sediments of a common lithology are deposited within a basin, they tend to compact and align along horizontal planes. This "packing" and alignment of sediment grains and particles also allows for easier water movement along the bedding direction and inhibits the movement potential across the bedding planes.

Within the current FCP groundwater flow model layers 1 and 2 (representing the UBFU) and layers 4 and 5 (representing the LBFU), the vertical anisotropy ratio was set to 10:1 representing interbedded coarse and fine grained material. For layer 3 (representing the MFGU), the ratio was set higher at 100:1 to reflect the extremely low vertical conductivity of the clays within this unit. This ratio was established during model calibration and was increased from 10:1 to match shallow water level responses from Gila River recharge. For model layers 6 through 10, the vertical hydraulic conductivity anisotropy ratio was kept at 1:1 to represent the nature of the fractured, crystalline, non-basin fill oxide and sulfide geologic units. Because these layers do not contain the interbedded fluvial deposits of the overlying units and water moves through fracture systems that are not necessarily horizontally oriented, it was assumed that there was no significant vertical anisotropy in these formations.

#### **Aquifer Tests used in Support of the Groundwater Flow Model**

USEPA asked that we provide a summary of aquifer tests that were used to support hydraulic parameterization of the current FCP groundwater flow model. During preparation of the current groundwater flow model, Brown and Caldwell reviewed the results of 26 aquifer tests conducted on the FCP site during 1995 in support of the original UIC and APP applications, and 11 production wells located within the model domain but outside the FCP site. These aquifer test results were compared to aquifer properties used to support the Pinal Active Management Area (AMA) groundwater flow model published by ADWR (1990).

Comparison of the aquifer test results to the Pinal AMA groundwater flow model aquifer properties showed that the aquifer properties used by ADWR (1990) to represent the alluvial units overlying the FCP site and surrounding the FCP site were in general agreement. However, ADWR (1990) treated the Oxide Bedrock Unit as impermeable bedrock.

The aquifer properties published by ADWR (1990) were used for alluvial units overlying or adjacent to the Oxide Bedrock Unit. Although ADWR (1990) treated the Oxide Bedrock Unit as impermeable, aquifer testing and operational testing conducted at the FCP site has demonstrated that the Oxide Bedrock Unit will produce groundwater when pumped, although at rates significantly lower than overlying UBFU and LBFU.

Aquifer parameters developed from aquifer tests conducted in 1995 within the Oxide Bedrock Unit were used to represent the Oxide Bedrock Unit within the current groundwater flow model. A database containing aquifer test results for all of the aquifer tests conducted in the Oxide Bedrock unit is included on a compact disc attached to this letter. A report prepared by Golder and Associates (Golder, 1996) describing aquifer test analyses and results is also included on the compact disc accompanying this letter.

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Please feel free to contact me at (520) 374-3984 with any questions you may have regarding the content of this letter.

Sincerely,

CURIS RESOURCES (ARIZONA) INC.



Daniel Johnson  
Manager, Environment and Technical Services

References

ADWR, 1990. *Pinal Active Management Area Regional Groundwater Flow Model, Modeling Report No. 2.*

Golder, 1996. *Analytical Interpretation of hydraulic Tests at the Florence Mine Site for Magma Copper Company, Florence In-Situ Leaching Project.*